Glass and Ceramics, Vol. 70, Nos. 3 – 4, July, 2013 (Russian Original, Nos. 3 – 4, March – April, 2013)

UDC 666.199:621.74

STONE-CAST WARE

A. B. Koldaev[1]

Translated from *Steklo i Keramika*, No. 3, pp. 23 – 28, March, 2013.

On the basis of physical-chemical and decorative properties stone casting can be used successfully in manufacturing interior and exterior facing of buildings and structures, paving stones, architectural construction, art objects and sculptures as well as commercial construction in a corrosive medium.

Key words: natural stone, stone casting, properties, application.

The existing natural finishing stones can be divided into two large groups according to the chemical composition of the constituent mineral stones: stones with a silicate anionic group and stones with a carbonate group of anions.

The silicate anionic group includes igneous rocks (granites, gabbro, basalts, labradorites and others) as well as metamorphic rocks (quartzites, gneisses and sandstones). The minerals making up these rocks are silicates (complex crystalline salts of silicic acid) or crystalline silicon oxide (quartz), chemically very strong, inert compounds.

The carbonate anionic group includes sedimentary rocks (dolomite, limestone, serpentinite, shell rock, chalk and others) as well as metamorphic rocks (marble, schist and marbleized limestone). Chemically, the minerals comprising these rocks are carbonates — crystalline salts of a weak carboxylic (carbonic) acid, compounds that easily decompose in chemical reactions with acids and solutions of their salts. For this reason, such stones are considered to be chemically unstable.

The natural stones (igneous, sedimentary and metamorphic rocks) currently used for finishing buildings have, together with all their undoubted advantages, the following drawbacks:

– natural stone obtained from one deposit is characterized by a surface with very definite color, pattern and texture; natural stones from different deposits are used to obtain the full range of colors required for finishing materials in construction; for all the richness of the existing reserves of natural finishing stones the complexity and high cost of developing a mine and transporting stones from new deposits makes natural stone materials with new colors inaccessible for purely economic reasons;

– a stone surface is multi shaded because igneous rocks (granites, gabbro, basalts, labradorites and others) have a nonuniform polymineral composition;

– igneous rocks (granites, gabbro, basalts, labradorites and others) possess elevated radioactivity due to the presence of secondary highly active solid radioisotopes of cesium, potassium, radium and thorium; even small dust-like particles of such rock entering the human body can do extremely serious harm to health even at low doses; studies show that in igneous rocks, such as granite, gabbro and others, the radioactivity is distributed very nonuniformly within layers of the rock mass, which makes it very likely that radioactive materials will enter the human body;

– the use of stones from the carbonate anionic group, which chemically are actually complex salts of chemically weak carbonic acid, specifically, marble, dolomite, limestone, shell stone, schist and other rocks, is limited by their inadequate chemical stability with respect to the aggressive gaseous components of the atmosphere, automobile emissions and different industrial emissions as well as weak chemical stability with respect to solutions of the salts of strong acids: chlorides, sulfates, iodides and others, which are also present in the form of a salt spray in the ambient atmosphere; the chemical stability of stone articles is especially urgent for large cities (megalopolises), such as Moscow, and coastal cities, such as, St. Petersburg or Vladivostok.

In summary, considering the large volumes of stone used in construction, obtaining nonradioactive and uniformly colored stone material with physical-chemical properties identical to or surpassing those of granite and a wide range of possible colors and shades is an urgent problem.

At the present time the following materials simulating natural stone are on the market:

[1] Tekhno-M Scientific-Industrial Company, JSC, Moscow, Russia (e-mail: akold@rambler.ru).

– ceramic granite – ceramic tile manufactured by the conventional technology and used to imitate stone;

– stone tile based on cement as binder and sand fill;

– agglomerate stone based on sand as fill and binder in the form of chemical polymer acryl or alkyd resins;

– material based on a mixture of sand and cullet.

Ceramic tile imitating granite is used mainly inside rooms as a facing material and floor covering. The material does not have adequate strength, freeze resistance or shock resistance for exterior use. Decoratively, ceramic tile is inferior to natural stone.

Material based on a mixture of sand and cullet is a heterogeneous mixture of sand with glass, as a result of which it is mechanically and chemically weak. This material is not widely used in Russia and other countries.

Material based on sand as fill and a binder in the form of chemical polymer acryl or alkyd resins is also used inside rooms as a facing material and floor covering. A serious drawback of this material is its flammability; when it burns large quantities of toxic products are released. In the USA and many countries of Western Europe it is against the law to use such material in residential and public buildings.

Tile based on sand and cement as binder is quite widely used inside rooms and in open spaces to finish and face buildings and on sidewalks, surfaces and roads. Sand and cement based tile is greatly inferior to natural stone. The binding properties of cement mixed with sand are due to the formation of water crystal hydrates, so that the body formed as the mixture solidifies is quite sensitive to moisture, including hygroscopic, penetrating through the pores in the material. For this reason a tile based on sand and cement is physically and chemically greatly inferior to igneous natural stone, for example, granite.

Considering the characteristics of stone articles, in large cities throughout the world predominately natural stone from igneous rocks is used for paving public areas. It should be noted that in repairing city roads the natural stone embedded in pavement can be removed and then used to lay the pavement anew. When sand- and cement-based pavement is used it is impossible to reuse the material.

The use of natural igneous rock and sand-and-cement tile as construction and finishing stone has one other feature: it is practically impossible to fake natural stone; all imitations of natural finishing stones are easily distinguished from natural stones. In the case of tile based on sand and cement, as a rule, it is impossible for the customer to control the quality of the material produced; all deficiencies manifest several years after the article is installed.

The cost of all finishing construction materials listed above is pretty much the same and is determined, as a rule, by the decorative-artistic properties of a particular material. A material with high decorative properties is more expensive and a material with average artistic characteristics is less expensive. This is true for all natural stones, sand-and-cement tile and materials based on sand and polymer resins. Depending on its decorative user properties, natural stone occupies a price niche in the market as the least expensive material and most expensive stone.

Stone casting reproduces under industrial conditions the natural conditions for the crystallization of stones with the optimal and required composition of the material. This gives a stone structure that is completely identical to natural granites and other strong igneous rocks.

In terms of the technological operations and equipment used stone casting technology is closest to glass production technology. The main difference of stone casting from glass production is that a completely crystalline article made from stone is formed at the output of the production process.

The raw materials base for obtaining finishing material by stone casting consists of natural minerals — sand, dolomite and chalk; soda ash is also used.

The crux of the method of stone casting is melting raw material at temperatures 1500 – 1600°C, cooling melt and crystallization of the melt. The material obtained in this manner is completely crystalline and contains no foreign chemical compounds and substances as the binding component. The pattern of cast-stone surfaces is not repeatable, just as in the case of natural stones, and the surface structure of cast stone is grainy, as is characteristic for natural stones. If necessary, stone cast material can be easily cut, ground or polished using special tools which are conventionally used for working natural stones: granite, marble and other rocks.

Materials obtained by stone casting have been used in the following objects in Moscow: decorative wall elements, Spasskaya and Nikol'skaya towers in the Moscow Kremlin (1972 – 1976), facing of the ground floors of apartment buildings in Tushino rayon (1983 – 1987) and elsewhere. The production of stone cast construction material was previously organized at the Moscow Stone Works (Dolgoprudnyi) and Konstantivnovskii Glass Works (Donetsk Oblast', Ukraine). There are no stone casting production lines at these enterprises at the present time.

Stone-cast material has been used to fabricate decorative elements of the white battlements and Spasskaya tower at the Moscow Kremlin (Fig. 1). Evidently, this is the latest successful application of white, locally produced, construction stone in Moscow. The Podol'sko-Myachkovskoe deposit of white natural limestone, owing to which the capital was famously dubbed "white stone," was exhausted at the beginning of the 18th century. Later, stone-cast material was colored by introduced mineral pigments, which were identical to the coloring components of natural stones.

Today, stone casting is the only accessible method for reviving the historical tradition of using white stone in construction and restoration in Moscow.

Stone-cast material was used quite often in the past. The currently operative standard GOST 23668–79 "Paving stone for road surfaces" contains norms for sizes and properties not only for igneous rocks (natural stone) but also "stones cast from slag and fused rocks," i.e., for stone casting.

Stone-cast materials are now used mainly for technical purposes (insulating pipes from corrosive liquids), for which

Fig. 1. Stone-cast decorative elements — white battlements and Spasskaya tower in the Moscow Kremlin.

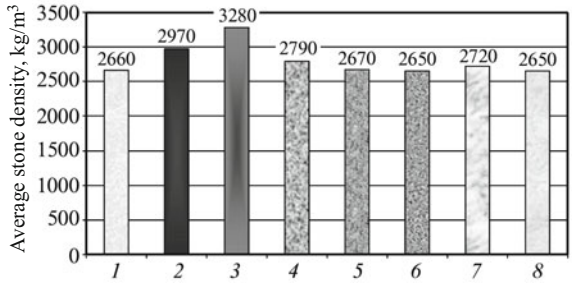

Fig. 2. Average density of stone. GOST 9479–98 establishes the requirements for the density of stone for strong rocks: ≥ 2500 kg/m^3; *1*) stone casting; *2*) Slipchitskoe gabbro; *3*) Yenskii gabbro-norit; *4*) Vozrozhdenie granite; *5*) Tokovskii granite; *6*) Pavlovskii (Shkuratovskii) granite; *7*) Kibik-Kordonskii marble; *8*) Genaldonskii dolomite.

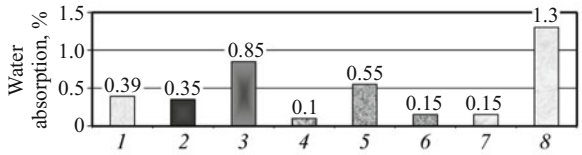

Fig. 3. Water absorption of stone (by weight): GOST 9479–98 requirements for strong rocks: ≤ 0.75%; *1*) stone casting; *2*) Slipchitskoe gabbro; *3*) Yenskii gabbro-norit; *4*) Vozrozhdenie granite; *5*) Tokovskii granite; *6*) Pavlovskii (Shkuratovskii) granite; *7*) Kibik-Kordonskii marble; *8*) Genaldonskii dolomite.

basaltic stone-cast material obtained by melting comminuted rock is used. Stone-cast basaltic material is also produced in Russia.

Cast stone made without specially added mineral colorants (transition metal oxides) is snow white, which makes it possible to use such a material for manufacturing exterior and interior facing of buildings, pavement and sidewalk slabs and areas, sculptures, statues and decorative elements. The possibility of changing the color of a material by varying the amount and type of colorant and changing its degree of homogenization in the main material and the use of mixed colorants make it possible to attain an almost infinite number of color and structural compositions of a stone surface. Since the cast stone obtained is completely crystalline and contains no other components (chemical polymers, cement, glass and so forth), the surface structure of such stone has the grainy pattern characteristic for natural stones (photographs of cast-stone samples are displayed in the color inserts).

Articles made of natural stone can be machined only with expensive diamond tools. For this reason up 80% of the price of natural stone is determined by the cost of the consumable diamond tool; in addition, for large stone articles the diamond tool fraction reaches 98% of the price.

Stone casting makes it possible to eliminate completely or reduce significantly the machining of stone.

Stone casting has the following advantages:

– availability in any color, including rare and especially rare colors (white, lilac, turquoise and others);

– high decorative-artistic properties;

– high strength, excellent freeze resistance, chemical stability, shock resistance, durability and complete absence of radioactivity;

– availability of three-dimensional decorative stone articles for finishing buildings and for artistic purposes at prices far below existing prices;

– availability of large-size stone articles more than 2 m long and thin articles less than 10 mm thick (full-scale serial production).

A series of studies was conducted to determine properties of cast stone, such as the density, water absorption, compression strength in dry and water-saturated states, durability, shock-, acid-, salt- and freeze-resistance and the specific effective activity of natural radionuclides. Tests of cast stone were performed according to GOST 30629–99; the properties of stone materials were evaluated according to the requirements for strong natural stone following GOST 9479–98.

The test results obtained from stone-cast samples compared with the properties of natural rocks — gabbro, granites, marble and dolomite — are presented in Figs. 2 – 9. According to these figures the average density of the cast-stone samples was 2660 kg/m^3 with very low water absorption — 0.39% (see Figs. 2 and 3). According to the compression strength (see Fig. 4), which reaches 345 MPa, this material can be classified as a high-strength stone, significantly surpassing the standard requirements — 120 MPa. The abradability of cast stone is 0.5 – 0.6 g/cm^2 (see Fig. 5),

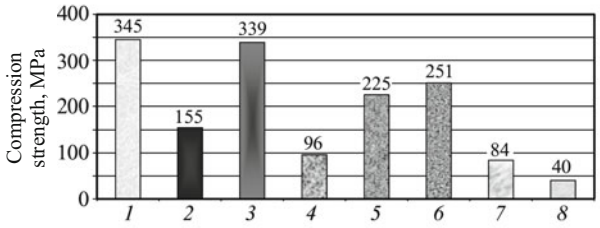

Fig. 4. Compression strength of dry stone. GOST 9479–98 requirements for strong rocks: ≥ 120 MPa; *1*) stone casting; *2*) Slipchitskoe gabbro; *3*) Yenskii gabbro-norit; *4*) Vozrozhdenie granite; *5*) Tokovskii granite; *6*) Pavlovskii (Shkuratovskii) granite; *7*) Kibik-Kordonskii marble; *8*) Genaldonskii dolomite.

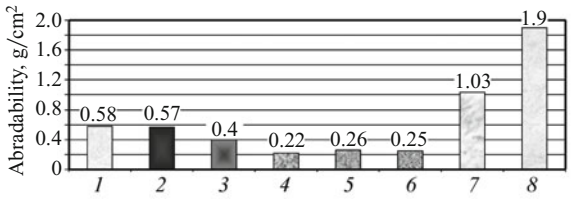

Fig. 5. Abradability. GOST 9479–98 requirements: ≤ 0.5 g/cm^2 with significant and very significant action, ≤ 1.0 g/cm^2 moderate action; *1*) stone casting; *2*) Slipchitskoe gabbro; *3*) Yenskii gabbro-norit; *4*) Vozrozhdenie granite; *5*) Tokovskii granite; *6*) Pavlovskii (Shkuratovskii) granite; *7*) Kibik-Kordonskii marble; *8*) Genaldonskii dolomite.

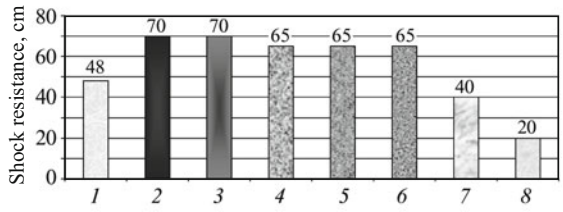

Fig. 6. Shock resistance of stone. GOST 9479–98 requirements: ≥ 50 cm for strong rocks, ≥ 40 cm for average-strength rocks; *1*) stone casting; *2*) Slipchitskoe gabbro; *3*) Yenskii gabbro-norit; *4*) Vozrozhdenie granite; *5*) Tokovskii granite; *6*) Pavlovskii (Shkuratovskii) granite; *7*) Kibik-Kordonskii marble; *8*) Genaldonskii dolomite.

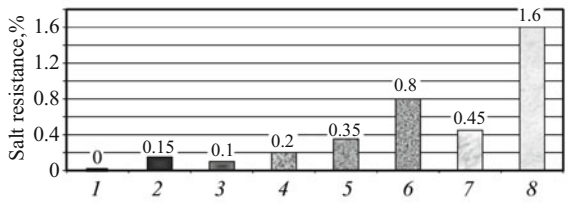

Fig. 7. Salt resistance (mass loss) of stone. GOST 9479–98 requirements: ≤ 5%; *1*) stone casting; *2*) Slipchitskoe gabbro; *3*) Yenskii gabbro-norit; *4*) Vozrozhdenie granite; *5*) Tokovskii granite; *6*) Pavlovskii (Shkuratovskii) granite; *7*) Kibik-Kordonskii marble; *8*) Genaldonskii dolomite.

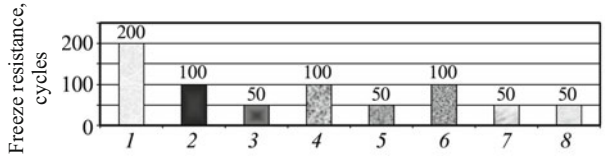

Fig. 8. Freeze resistance (number of cycles with no decrease of strength) of stone. GOST 9479–98 requirements depending on the climatic conditions ≥ 15, 25, 35, 50, 100, 150 and 200 cycles; *1*) stone casting; *2*) Slipchitskoe gabbro; *3*) Yenskii gabbro-norit; *4*) Vozrozhdenie granite; *5*) Tokovskii granite; *6*) Pavlovskii (Shkuratovskii) granite; *7*) Kibik-Kordonskii marble; *8*) Genaldonskii dolomite.

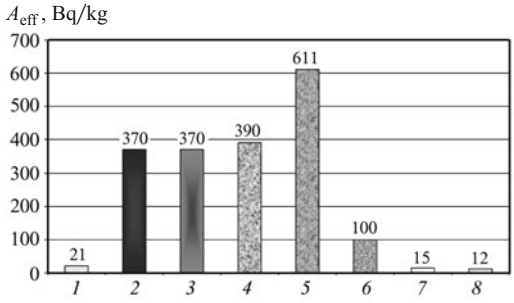

Fig. 9. Specific effective activity of natural radionuclides A_{eff}. GOST 9479–98 requirements: ≤ 370 Bq/kg for interior and exterior facing of public buildings; *1*) stone casting; *2*) Slipchitskoe gabbro; *3*) Yenskii gabbro-norit; *4*) Vozrozhdenie granite; *5*) Tokovskii granite; *6*) Pavlovskii (Shkuratovskii) granite; *7*) Kibik-Kordonskii marble; *8*) Genaldonskii dolomite.

which meets the requirements for materials used for paving, flooring and staircases, which are subjected to significant and very significant mechanical action.

In tests of stone casting for salt resistance (see Fig. 7) no decrease of strength or mass loss occurred after exposure to a sodium sulfate solution. This makes it possible to recommend stone casting for ground-floor facing coming into contact with soil or for facing of pools containing sulfate or sea water. Under the action of another corrosive component — concentrated and dilute sulfuric acid the strength loss did not exceed the admissible norm ≤ 7% set in GOST 473–81. The high acid resistance of stone casting is necessary for acid-resistant materials used for facing of special reservoirs, pipes and machine room floors of CGP, HEPP and NPP and other enclosures.

The stone material obtained by casting also possesses good freeze resistance (see Fig. 8), the freeze resistance grade is higher than F200, which meets the high requirements for exterior facing and other types of stone products.

The value of another property normalized by an industry-wide standard is the shock resistance (see Fig. 6) of stone casting, which is the same as that of natural stones. The high

resistance to the corrosive components of atmospheric precipitation and very high freeze resistance in the domestic climate make it possible to use such finishing material in all possible methods for construction and finishing of buildings.

In contrast to natural granite, stone casting has a very low specific activity of natural radionuclides (see Fig. 9), which makes it possible to use it for exterior and interior finishing of buildings and enclosures.

In summary, on the basis of the physical-chemical and decorative properties stone casting can be used successfully for manufacturing interior and exterior facing of buildings and structures, paving stones, architectural-construction elements, art objects and sculptures. Since stone casting meets the requirements for an acid-resistant material it can be used in commercial construction under exposure to corrosive media.

REFERENCES

1. *GOST 9479–98. Blocks of Rocks for Manufacturing Facing, Architectural-Construction, Memorial and Other Articles: Technical Conditions* [in Russian], Moscow (1998).
2. *GOST 30629–99. Facing Materials and Articles made from Rocks: Testing Methods* [in Russian], Moscow (1999).
3. *GOST 473–81. Chemically Stable Ceramic Articles* [in Russian], Moscow (1981).
4. *GOST 23668–79. Paving Stone for Road Surfaces: Technical Conditions* [in Russian], Moscow (1979).
5. *GOST 6666–81. Border Stones from Rocks* [in Russian], Moscow (1981).